Real-Time Drill-Bit VSP from an Offshore Platform

James W. Rector III, Western Atlas International Inc.; and D. S. Weiss, Chevron USA

SUMMARY

Two offshore Tomex® Seismic-While-Drilling[sm] surveys were acquired on an offshore platform in November 1988 and January 1989. The Tomex method uses the vibrations generated by the drill bit while drilling as a downhole seismic energy source. Hence, the technique is often described as drill-bit VSP. The purpose of the first drill-bit VSP survey was to test whether the technique would work in a deep offshore environment, since previous surveys had been confined to land wells and transition zones. The data quality recorded during the first survey was very good. The time-depth (T-D) curve obtained from the data compared favorably with the T-D curve from a conventional velocity survey. In a second offshore survey conducted off the same platform, the T-D curve was used to continuously monitor the position of the drill bit with respect to the 3-D seismic time section. With the help of this information, the pierce point location on the target formation was maintained within 5 ft of the desired pierce point.

INTRODUCTION

Prior to the commencement of development drilling from the platform, it was recognized that a very strong, low-velocity zone was present over the crest of the anticlinal structure. Velocity surveys from exploration wells indicated that interval velocities varied by as much as 50% within this low-velocity zone. At a depth of 5000 ft, this results in a potential depth uncertainty of 400 ft. In an integrated effort to resolve this subsurface velocity variation, several velocity surveys were programmed for the early development wells. Two offshore drill-bit VSP surveys were included in the various velocity surveys that were collected in this early drilling phase. The first survey, performed on study well 1, was an initial test of the drill-bit VSP technology in an offshore environment. The second survey, on study well 2, was used to provide real-time positioning of the drill bit within the 3-D seismic time section.

The drill-bit VSP technique was attractive in this situation because of its advantages over conventional velocity surveys. All of the wells from the platform were deviated, so a moving seismic source was typically required for shooting a conventional vertically-incident velocity survey. The drill-bit VSP method circumvented the need for a seismic source. It was also recognized that there was a need for monitoring the position of the drill bit with respect to the 3-D time seismic time section. The capability for having real-time velocity surveys with drill-bit VSP was particularly attractive on highly deviated holes drilled into areas of no velocity control such as study well 2.

THE TOMEX METHOD

The drill-bit VSP technique uses the natural vibrations created by the rotating drill bit during drilling as a downhole energy source. Data are acquired without any downhole instrumentation and the data recording does not interfere with the drilling process. The drill-bit generated vibrations are received by a reference-sensor attached to the top of the drillstring and by geophones or hydrophones located at the surface. The reference sensor signal is cross-correlated against the received signal to compute arrival times of events and to attenuate incoherent noise (Rector et. al., 1988). The cross-correlated data are then processed to generate inverse-VSP data. This technique has been successfully utilized at over 25 wells on land within the continental United States. Results of a comparison with VSP data show nearly equivalent travel times and similar reflector images (Rector, et. al., 1988).

The drill-bit VSP technique has been used for a wide variety of applications. The ability to record data while drilling has provided real-time velocity surveys that have been used to tell drillers where the bit is located in terms of the seismic time section. In unpublished results, the drill bit-generated reflection energy has been used to look ahead of the drill bit for overpressure zones and lithology changes, and multi-offset drill-bit VSP surveys capable of imaging a 3-D volume of earth around the borehole have been used to delineate faults and measure dips near the borehole.

The advantages of the method are accentuated offshore. In particular the high cost of rig time on offshore wells for conventional velocity surveys and conventional VSP is eliminated. The risks associated with wireline operations in a borehole that is expensive, often highly deviated, and often poorly conditioned are also avoided.

SURVEY LAYOUT AND DATA COLLECTION

Figure 1 shows the subsurface geometry and the survey layout for study wells 1 and 2. A 5000 ft cable was deployed along the ocean bottom 750 ft below the sea surface. The cable was anchored with heavy chains to insure good coupling, and was marked with buoys. Three hydrophones were attached to the cable. These hydrophones were located at 1500 ft intervals from the platform.

Figure 2 shows the position of the hydrophones as determined after the surveys. The actual position of the hydrophones was determined by shooting a short grid of lines with a small airgun. The final position of the cable for study well 1 was determined to be about 20 degrees south of the intended position above the well path. This departure was believed to be due to navigation difficulties aboard the deployment vessel. In the subsequent survey on study well 2, improved navigation resulted in the correct positioning of the cable.

Drill-bit signals were recorded continuously on study wells 1 and 2. Cross-correlation functions between the pilot-sensor signal and each of the hydrophone signals were generated and then processed to generate a VSP-like display as discussed in Rector, et. al., (1988). The VSP-equivalent data over a section of the borehole from hydrophone sites 1 and 2 on study well 1 are shown in figure 3. This data quality is comparable to typical data quality observed on land wells acquired with drill-bit VSP. However, large geophone arrays are usually necessary on land to observe signals of this quality. Single hydrophones can be used offshore because there is less noise at the ocean bottom than at the earth's surface. The low frequency (<35 hz) nature of the data is typical of seismic data acquired in the region.

The direct-arrival energy, the counterpart to the VSP downgoing wave, is the first coherent energy appearing in the sections of figure 3. At hydrophone site 1, the direct arrival is strongest at the shallow depths and slightly decreases in amplitude as the drill bit moves away from the hydrophone. We believe this is due to spherical spreading and attenuation associated with longer, more oblique travel paths. At hydrophone site 2, the direct arrival is strong below a measured depth of 4000 ft and weak above 4000 ft. We believe that this amplitude variation is due to two effects: (1) the zone of low velocities and; (2) characteristics of the drill-bit radiation pattern. The velocity profile in the area predicted a critical reflection angle of 35 to 40 degrees, hence direct arrival energy was not observed at hydrophone site 2 above 3500 ft. Assuming that the drill bit generates most of its vibrations axially, the radiated P-wave direct-arrival signal from the drill bit will be strongest along the axis of the borehole and weakest perpendicular to this axis (White, 1965). Referring to Figure 4, the direct arrival at site 2 emerges within 10 degrees of a null in the radiation pattern above 4000 ft, so its amplitude will be less than 20% of its amplitude along the borehole axis. Below 4000 ft, the direct-arrival angle becomes more vertical and the direct-arrival amplitude recorded at hydrophone site 2 increases.

The downgoing energy following the direct arrival with a lag of 310 ms is the surface-ghost reflection. It has a polarity that is reversed from the primary energy. Ignoring spherical spreading and attenuation, the ghost will have an amplitude that is equivalent to the direct arrival for vertical incidence angles. At non-vertical incidence angles the ghost can be larger than the direct arrival due to transmission and radiation pattern effects. Hence the ghost is stronger above 4000 ft at hydrophone site 2 than is the direct arrival.

The radiation pattern of the drill bit in a deviated hole also predicts that the energy reflected from the shallow horizons will be stronger at hydrophone site 2 than at hydrophone site 1. This is apparent in figure 3, where there is a distinct upgoing arrival on hydrophone site 2 that intersects the direct arrival at a measured depth of 4000 ft. This arrival is not apparent at site 1.

COMPARISON WITH CONVENTIONAL VELOCITY SURVEY: STUDY WELL 1

Figure 5 shows a comparison of travel times computed from the drill bit VSP velocity survey and travel times from a conventional velocity survey. Tool and hole problems prevented conventional logging of the entire hole, so a direct comparison with conventional techniques could be made over a limited portion of the well. The travel times were measured by picking the peak of the direct-arrival wavelet recorded with drill-bit VSP and by picking the onset of energy in the direct-arrival wavelet from the conventional velocity survey wavelet. The travel times were corrected to vertical travel time by assuming a straight raypath between source and receiver. The vertical travel times from the drill-bit VSP, data were datum corrected from ocean bottom to sea level. The travel-time differences in the two measurements are generally less than 1%, resulting in a depth discrepancy of less than 50 ft. These differences can be explained by the lateral velocity variations in the area, the inaccuracies of a straight raypath assumption, the potential for anisotropy in the region, and random picking errors. The direct arrival wavelet was assumed to be zero phase for the signal resulting from the cross-correlation process of drill-bit VSP and minimum phase for the signal obtained from the conventional airgun survey. The inaccuracies of these wavelet phase assumptions may also have led to some discrepancies between the surveys.

RESULTS OF REAL-TIME VELOCITY SURVEY: STUDY WELL 2

Study well 2 was a highly deviated well drilled into an area of poor velocity control. A drill-bit VSP survey was recorded in the lower portion of the hole to continuously monitor the position of the drill bit relative to the seismic target zone. Twice daily, position time vs depth information was received in the development office to update the position of the bit in the 3-D seismic time section. With such poor velocity control in an area of strong lateral velocity gradients, the real-time velocity survey provided by the technique helped ensure that the drill bit was on track to the proper target location. If the velocity field had turned out to be significantly faster or slower than predicted, the penetration point at the main reservoir could have been as much as 200 ft higher or lower than predicted. As it turned out, the actual penetration depth was within 5 ft vertically from the desired location. The daily time-depth information was very useful in achieving this accuracy.

CONCLUSIONS

The first two Tomex surveys recorded offshore were successful. The data quality recorded in 750 ft of water was comparable to drill bit data quality recorded on land. The data quality is expected to be superior to land data quality when hydrophone groups are deployed instead of the single hydrophones utilized for these surveys. Time-versus-depth information from the technique compared closely with a conventional velocity survey performed on study well 1. The time-depth curve from study well 2 was used to continuously monitor the position of the drill bit with respect to the 3-D seismic time section. The pierce point of the target formation was maintained within 5 ft of the desired pierce point.

REFERENCES

Rector, J.W., B.P. Marion, and B. Widrow, 1988; Use of Drill-Bit Energy as a Downhole Seismic Source, SEG Expanded Abstracts, 1, 161-164.

White, J.E., 1965, Seismic Waves: Radiation, Transmission, and Attenuation. McGraw Hill, 302 p.

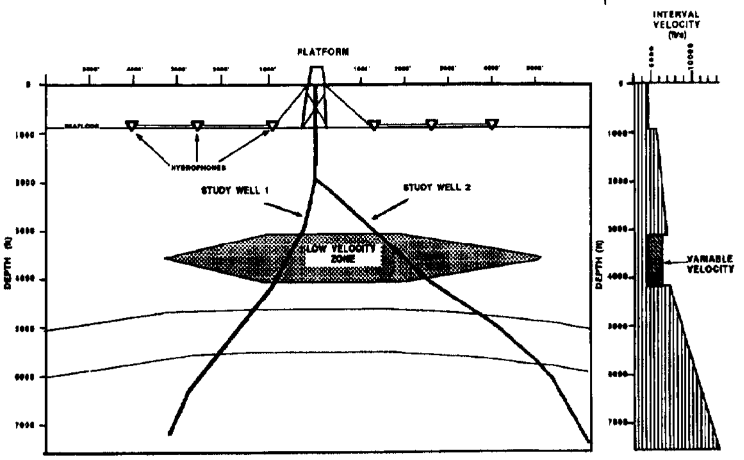

FIG. 1. Cross-section of Tomex® survey layout and well course on study wells 1 and 2.

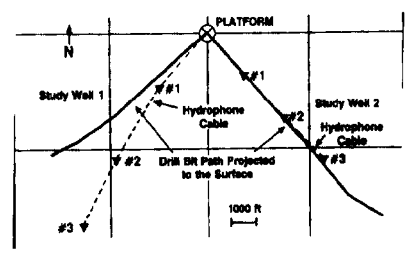

FIG. 2. Map view of layout and well course on study wells 1 and 2.

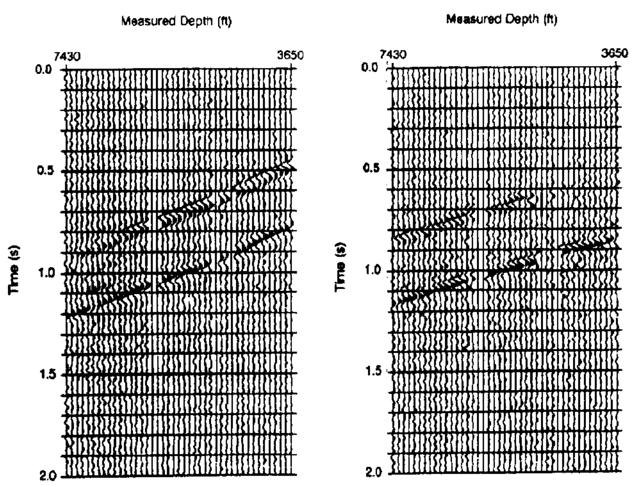

FIG. 3. Drill-bit VSP data from study well 1: sites 1 and 2.

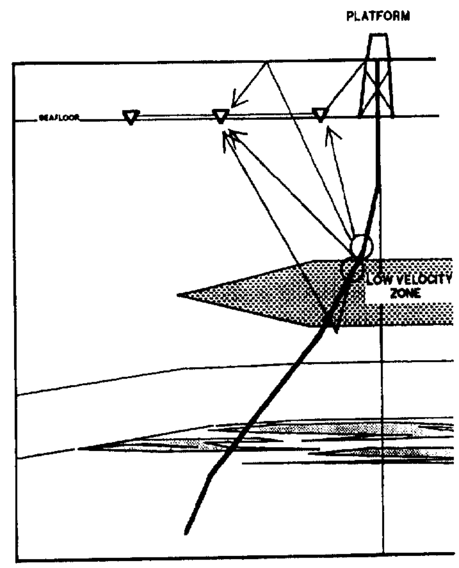

FIG. 4. Seismic *P*-wave radiation pattern and raypaths for drill bit acting axially on formation at study well 1.

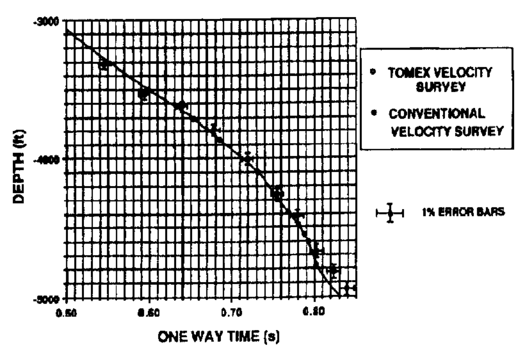

FIG. 5. Comparison of drill-bit VSP survey and conventional velocity survey time-versus-depth (T-D) curves: study well 1.